Argonne National Laboratory
HEP Theory Group

Overview of the Group Activities

C.E.M. Wagner

Argonne National Laboratory

KICP and EFI, University of Chicago

DOE Site Visit, HEP Theory Group, Argonne National Lab

September 4, 2012

Outline

- Composition of the HEP Theory Group
- Major research activities
- Research Highlights
- Invited Talks, Awards and Community Services

E. Berger

G. Bodwin

R. Boughezal

I. Low

F. Petriello

C. Wagner

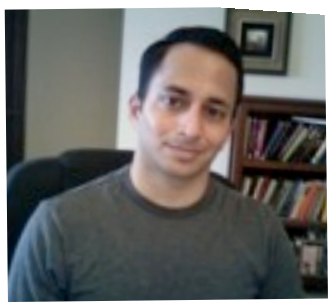
C. Zachos

S. Gori

P. Schwaller

M. Schulze

X. Liu



S. Mantry

H. Zhang

S. Becker

Argonne HEP Theory Group.

Higgs Physics

- Some of the most noteworthy contributions of the group are on Higgs physics.
- The cross sections and uncertainty estimates for Higgs production used by both the Tevatron and the LHC collaborations in their searches were derived by Argonne personnel.
- We examine the implications of the observed Higgs mass and production rates for well established beyond the SM scenarios, and analyze the properties that such scenarios must fulfill in order to describe the observed Higgs signals.
- We also study new methods for looking for the Higgs boson, as well as for the determination of the Higgs boson properties, and the possible differentiation of the Higgs scalar from other look-alike particles.

Top Quark Physics

- The top quark is the heaviest fundamental particle. It couples strongly to the Higgs and therefore is a relevant player in the electroweak symmetry breaking process

- The Tevatron data show an intriguingly large value of the top-quark forward-backward asymmetry. The LHC experiments measure a related top-charge asymmetry.

- The Theory Group is involved in the computation of top quark production processes, the analysis of new variables to study the top properties and the study of new physics models that can lead to an explanation of the Tevartron results.

Heavy-Quarkonium Physics

- A unique theoretical laboratory for understanding the interplay between perturbative and nonperturbative QCD.
- New theoretical concepts/techniques discovered by studying heavy-quarkonium production.
  - Important for understanding QCD in its own right.
  - Important to test/improve reliability of perturbative calculations.
  - Important for BSM calculations if new particles are composites.
- There is a great deal of activity in heavy-quarkonium physics at ATLAS, CMS, LHCb, ALICE, PHENIX, STAR, Belle, BESII.
- Scores of LHC quarkonium papers. Many more LHC results to come.
- Standard method for theoretical calculations of quarkonium decay and production: the NRQCD factorization approach.
  (G.T. Bodwin, E. Braaten, G.P. Lepage, PRD 51, 1125, 1995).

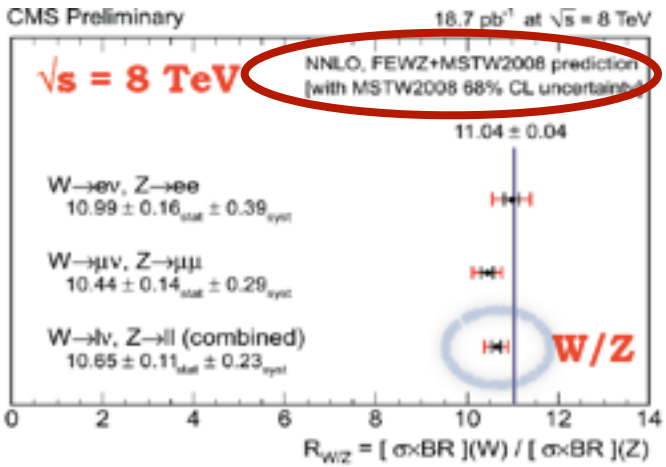
QCD and collider applications

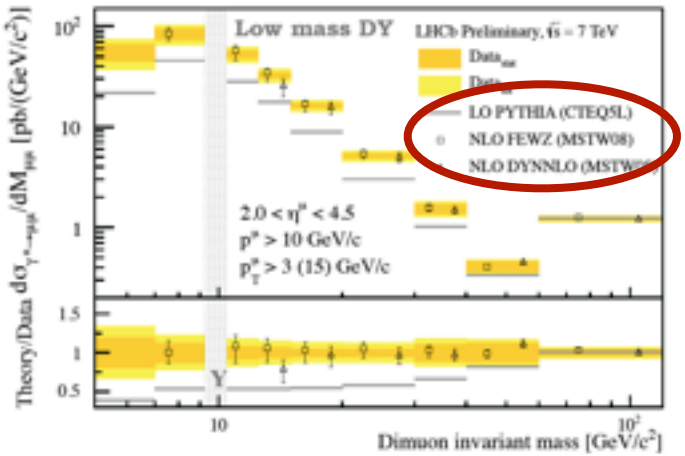
Broad goals: improve Standard Model predictions for observables at the LHC and other experiments to enable discoveries, and develop improved calculational techniques for QCD

- Continued development of the simulation code FEWZ (Fully Exclusive W and Z production); used by ATLAS, CMS, LHCb, CDF, D0 in their analyses

R. Gavin, Y. Li, S. Quackenbush, F. Petriello, arXiv:1201.5896,; Y. Li, F. Petriello, arXiv:1208:5967

From ICHEP 2012 plenary talk on EW physics:





- Development of an NNLO subtraction scheme powerful enough to use in computations of jet cross sections in hadronic collisions R. Boughezal, K. Melnikov, F. Petriello Phys. Rev. D85 (2012) 034025
- New applications of effective field theory to improve predictions for missing energy plus multi-jet backgrounds to LHC SUSY and dark matter searches X. Liu, S. Mantry, F. Petriello arXiv:1205.4465
- A method for determining the `Higgs' boson spin and CP with early data

R. Boughezal, T. LeCompte, F. Petriello arXiv:1208.4311, see R. Boughezal's talk

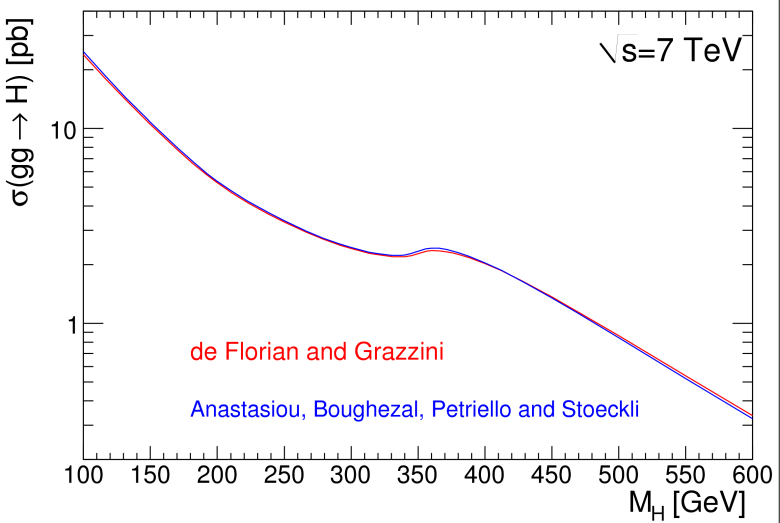
Higgs Physics

• Higgs Physics at the LHC: Argonne influence

- Provided the prediction for gg → H cross section at the Tevatron and the LHC
- Our predictions are the official cross sections used by both colliders

CERN Yellow Report 2011

CERN-2011-002



The Higgs boson is a CP-even scalar. So we need to measure the spin and CP properties of the new resonance. Suppose the Spin and CP properties check out, are we sure it is *the* Higgs boson?

NO. NEED TO MAKE SURE IT IS ALSO AN ELECTROWEAK DOUBLET!

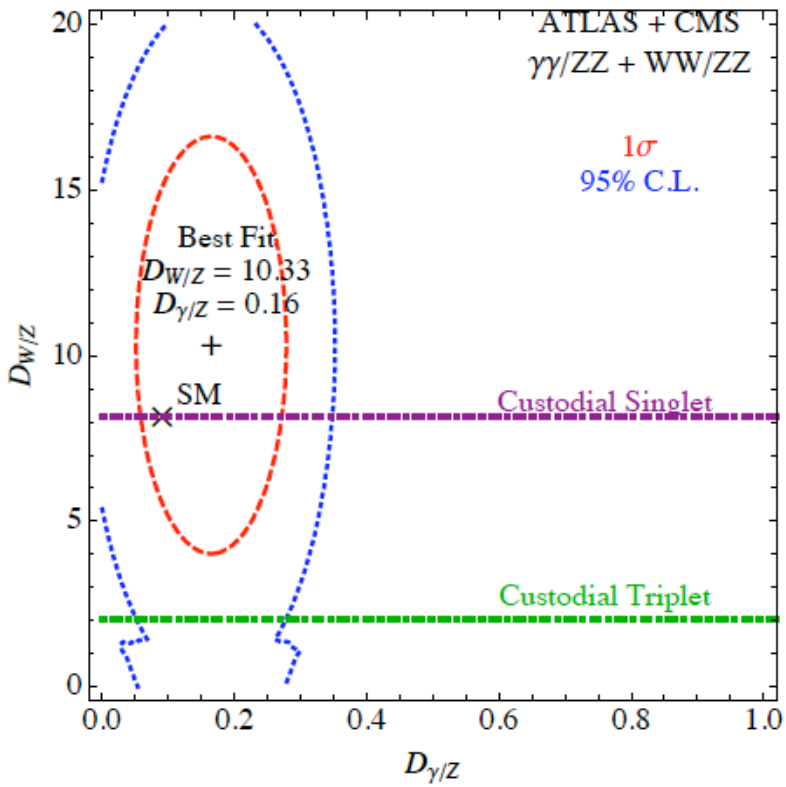
Key measurements to distinguish the Higgs from its imposters:

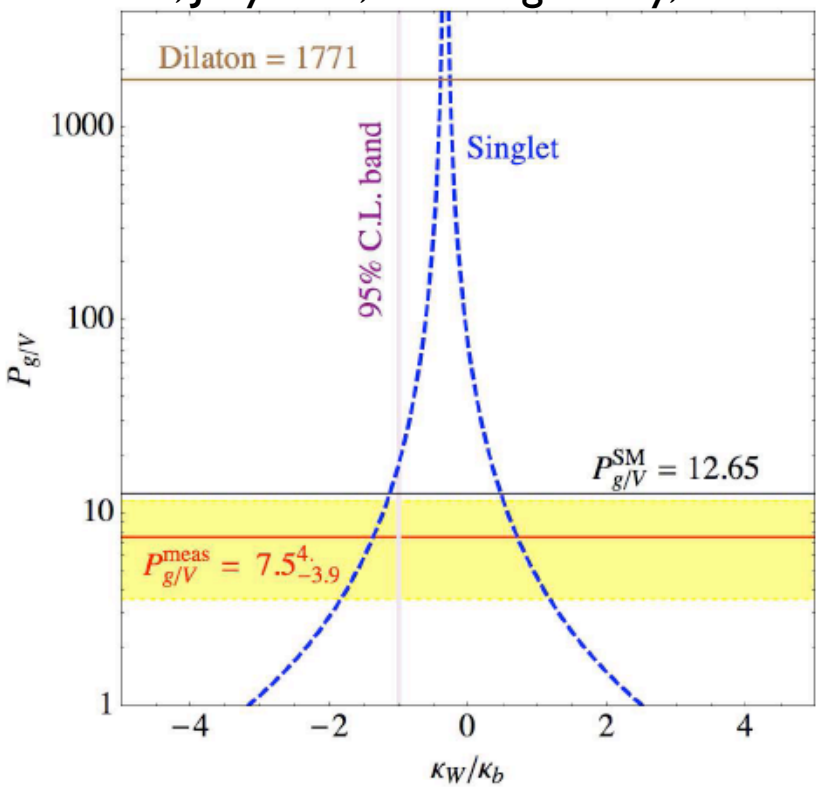
$$D_{W/Z} \equiv \frac{B\sigma_{gg}(WW)}{B\sigma_{gg}(ZZ)} = \frac{\Gamma(S \to WW)}{\Gamma(S \to ZZ)} ,$$

$$D_{\gamma/Z} \equiv \frac{B\sigma_{gg}(\gamma\gamma)}{B\sigma_{gg}(ZZ)} = \frac{\Gamma(S \to \gamma\gamma)}{\Gamma(S \to ZZ)} ,$$

$$P_{g/V} \equiv \frac{B\sigma_{gg}(\gamma\gamma)}{B\sigma_{\rm VBF}(\gamma\gamma)} = \frac{\sigma(gg \to S)}{\sigma(\rm VBF \to S)}$$

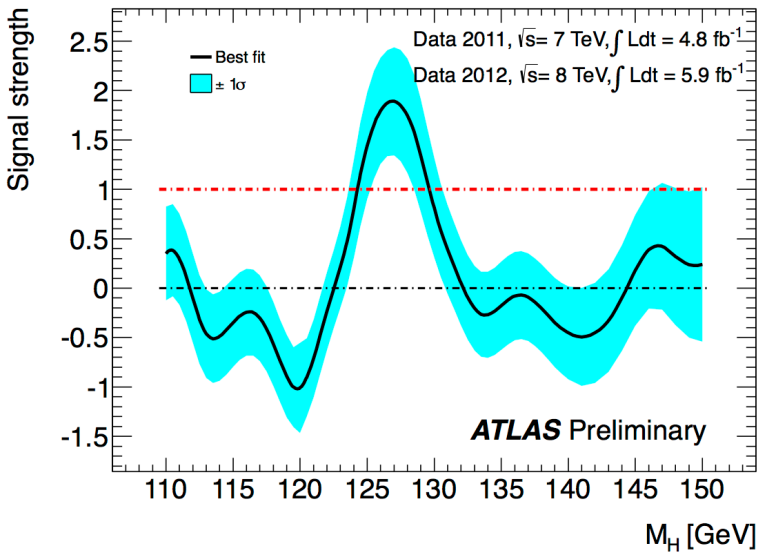
I. Low, J. Lykken, G. Shaughnessy, 1207.1093

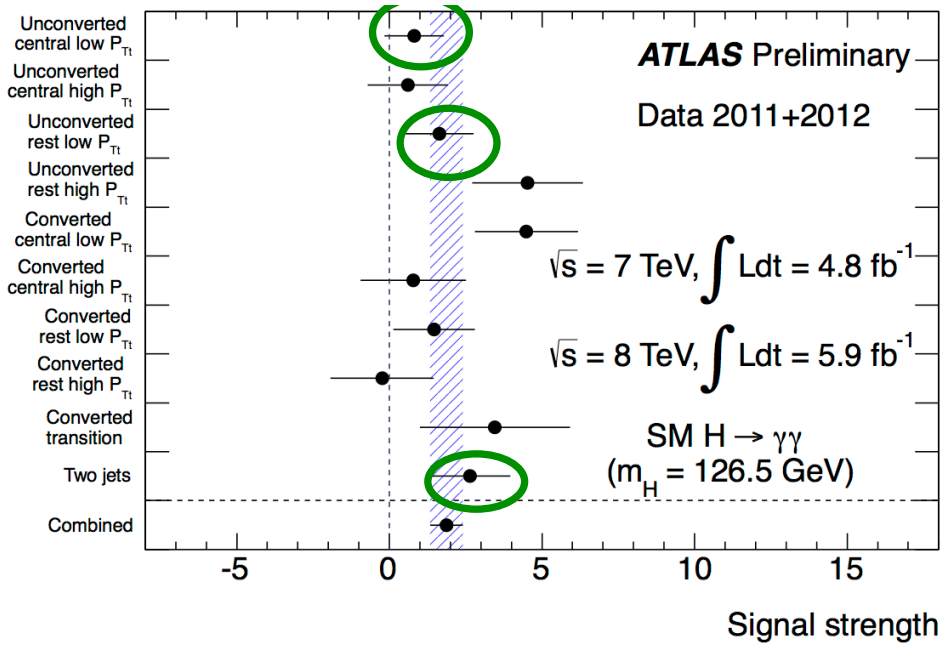




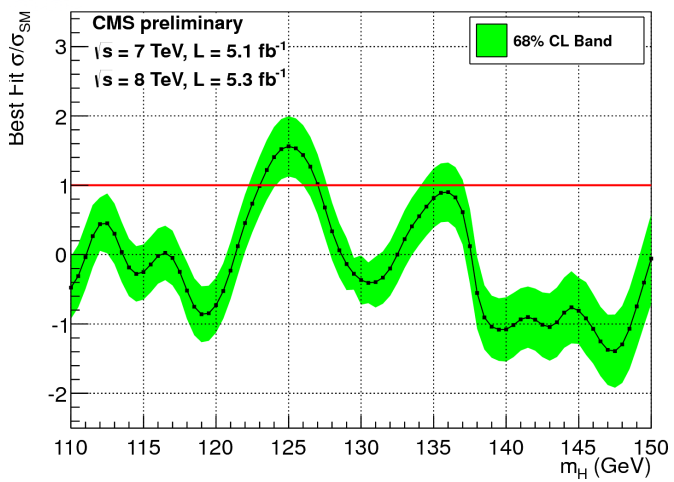
Best fit to diphoton production cross section is larger than the SM one in both experiments, but still consistent with it at the 2 σ level

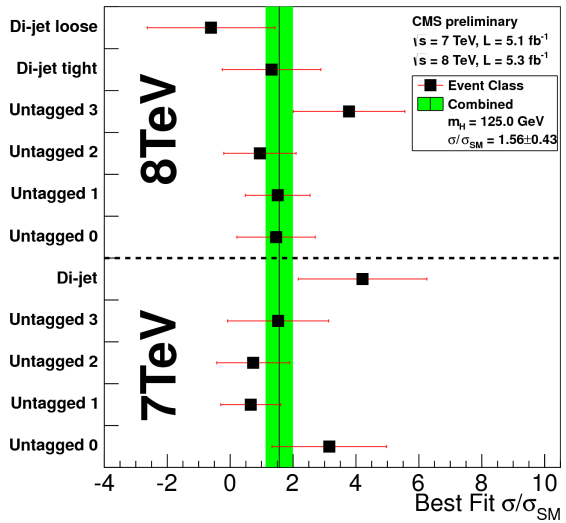
Best-fit value at 126.5 GeV:
μ=1.9 ± 0.5





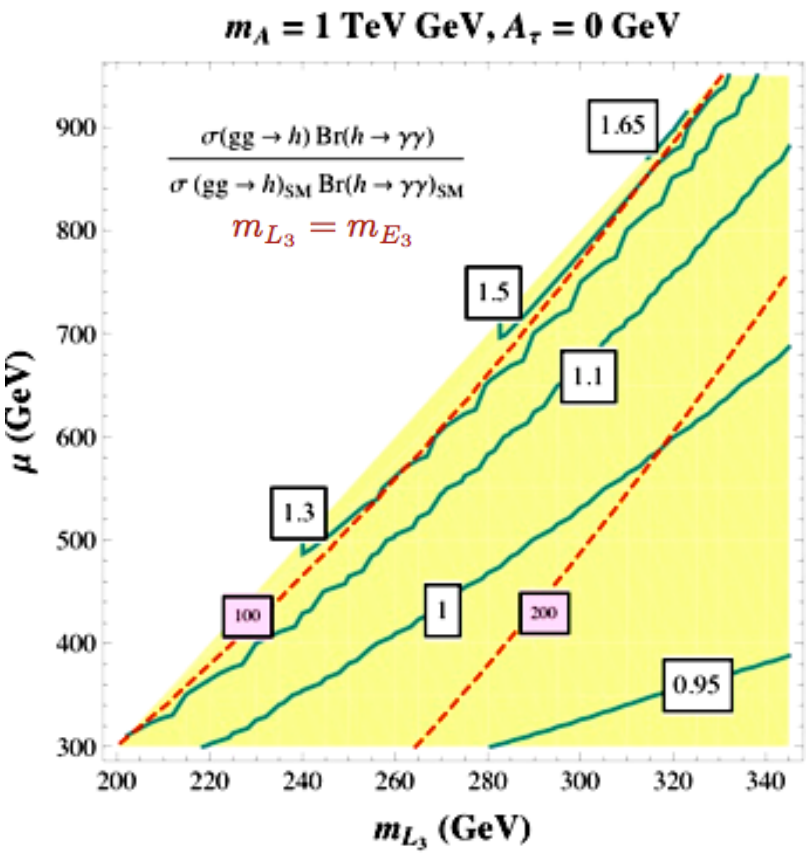
σ/σ_{SM} = 1.56±0.43 x SM





Higgs Production in the di-photon channel in the MSSM

Charged scalar particles with no color charge can change di-photon rate without modification of the gluon production process



$$\mathcal{M}^2_{\tilde{\tau}} \simeq \begin{bmatrix} m^2_{L_3} + m^2_\tau + D_L & h_\tau v(A_\tau \cos\beta - \mu \sin\beta) \\ h_\tau v(A_\tau \cos\beta - \mu \sin\beta) & m^2_{E_3} + m^2_\tau + D_R \end{bmatrix}$$

Light staus with large mixing [sizeable μ and tan beta]:

➔ **enhancement of the Higgs to di-photon decay rate**

Contours of constant

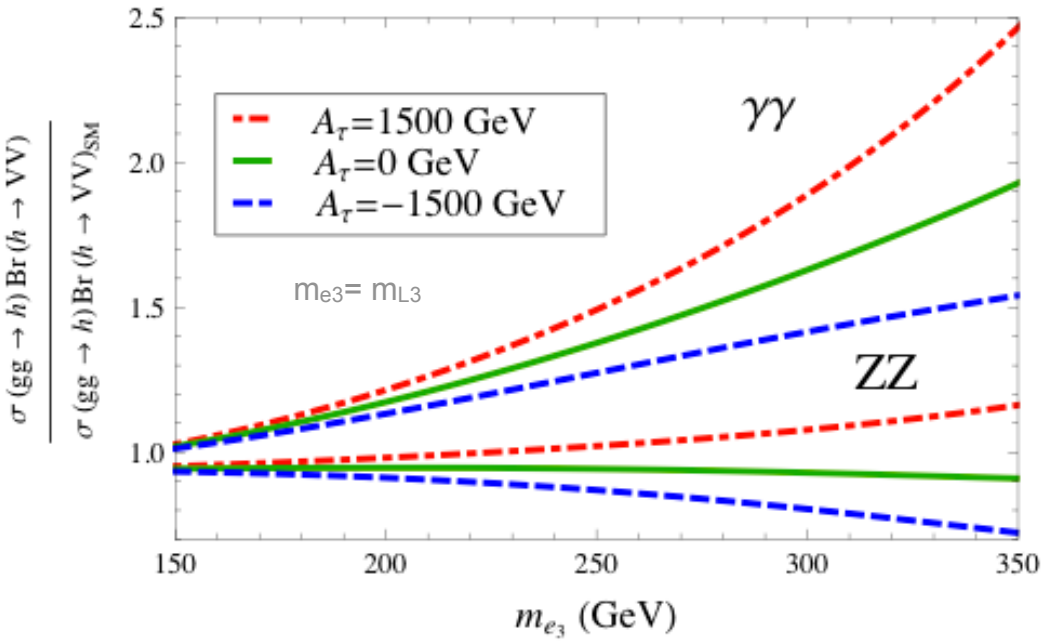
$$\frac{\sigma(gg \to h)\,Br(h \to \gamma\gamma)}{\sigma(gg \to h)_{SM}\,Br(h \to \gamma\gamma)_{SM}}$$

for $M_h \sim 125$ GeV

M. Carena, S. Gori, N. Shah, C. Wagner, arXiv:1112.336, +L.T.Wang, arXiv:1205.5842

Additional modifications of the Higgs rates into gauge bosons via stau induced mixing effects in the Higgs sector

M. Carena, S. Gori, N. Shah, C. Wagner, arXiv:1112.336,+L.T. Wang, arXiv:1205.5842



m_{Stau}~ 90 GeV; m_h~ 125 GeV

Important A_τ induced radiative corrections to the mixing angle α that defines the bottom coupling to Higgs
hbb ~ sinα/cosβ

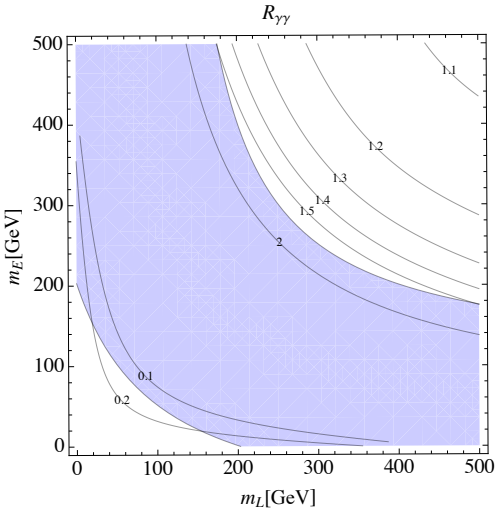
Small variations in BR [Hbb] induce significant variations in the other Higgs BR's

Gluon fusion production rate can be varied for light stops

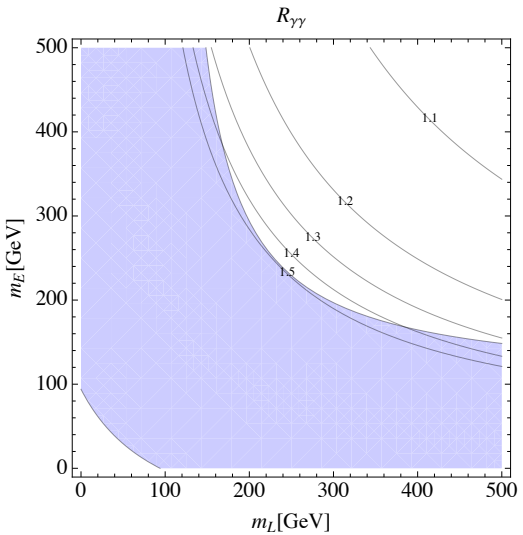
Model with a four generation leptons and their vector pairs.

Model can lead to the presence of Dark Matter and an enhanced diphoton rate

A. Joglekar, P. Schwaller, C.Wagner, arXiv: 1207.0345



$Y'_C = Y_C" = 1$



$Y'_C = Y_C" = 0.8$

$$\mathcal{L}_{h\gamma\gamma} = \frac{\alpha}{16\pi}\frac{h}{v}\left[\sum_i b_i \frac{\partial}{\partial \log v}\log\left(\det \mathcal{M}^\dagger_{F,i}\mathcal{M}_{F,i}\right) + \sum_i b_i \frac{\partial}{\partial \log v}\log\left(\det \mathcal{M}^2_{B,i}\right)\right] F_{\mu\nu}F^{\mu\nu}$$

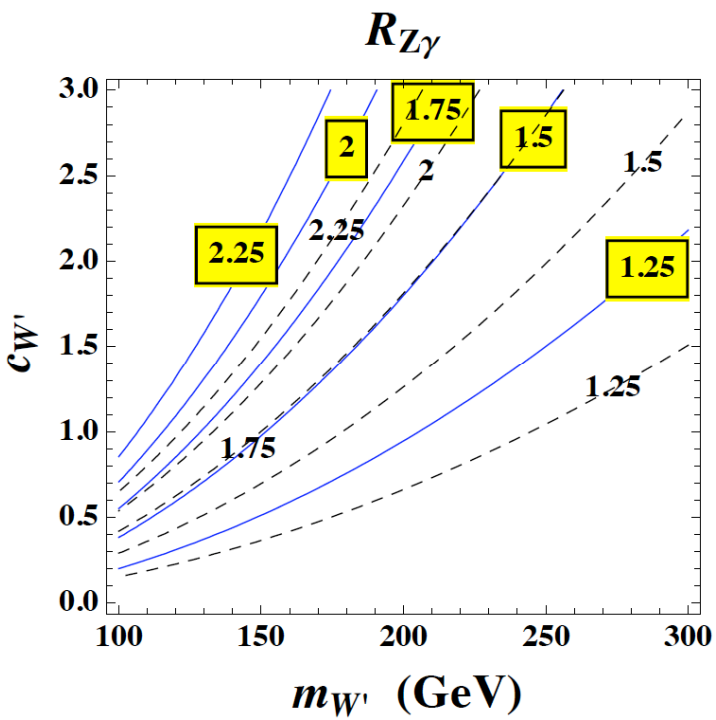
M. Carena, I. Low, C.Wagner, arXiv:1206.1082

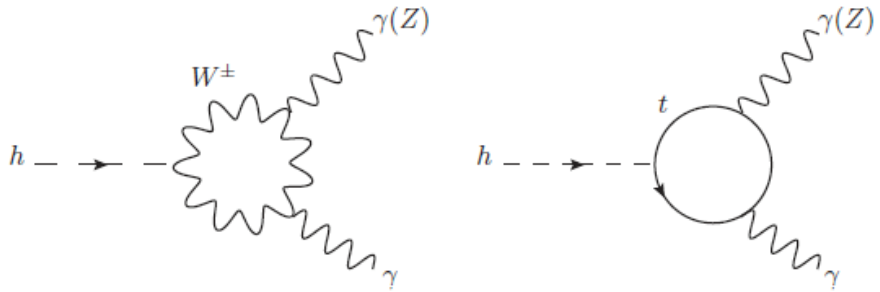
$$\mathcal{M} = \begin{pmatrix} Y'_c v & m_{\mathsf{L}} \\ m_{\mathsf{E}} & Y''_c v \end{pmatrix}$$

$$\frac{\partial \log(\mathrm{Det} M_f)}{\partial v} \simeq -2\frac{Y'_C Y_C" v}{m_L m_E - Y'_C Y_C" v^2}$$

There seems to be an enhancement in the diphoton channel coming from the partial decay width, as other channels see no enhancement.

Interestingly, whatever modifies the diphoton width will also modify the Z+Gamma width!





$$\mathcal{O}_{W'} = \frac{1}{2} c_{W'} g^2 H^\dagger H \, W'^{+}_{\mu} W'^{-\mu}$$

Dashed lines: Ratio of GammaGamma Width
Solid lines: Ratio of Z+Gamma Width

M. Carena, I. Low, C.E.M. Wagner, arXiv:1206.1082

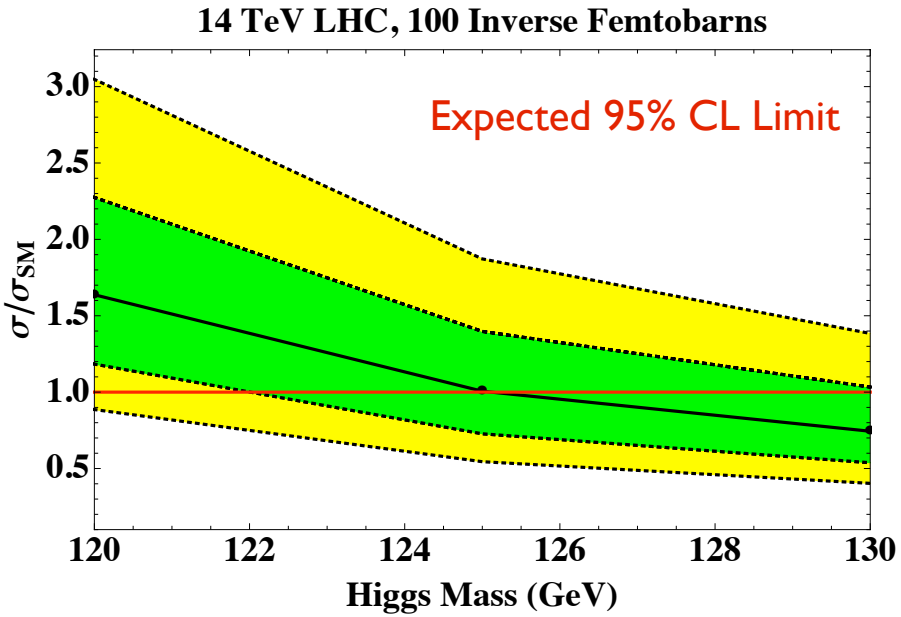
HIGGS TO Z GAMMA SEARCH

Jamie Gainer, Ian Low, Pedro Schwaller, Wai-Yee Keung, PRD 85, 015009 (2012)

- $\mathrm{BR}(h \to Z\gamma) \sim \mathrm{BR}(h \to \gamma\gamma)$ at $m_h \sim 125$ GeV

- Sensitive to new physics loops, important probe of electroweak structure, mostly neglected

- Problem: Larger background. Used invariant mass shape and angular distributions to improve sensitivity, realistic analysis including jet radiation

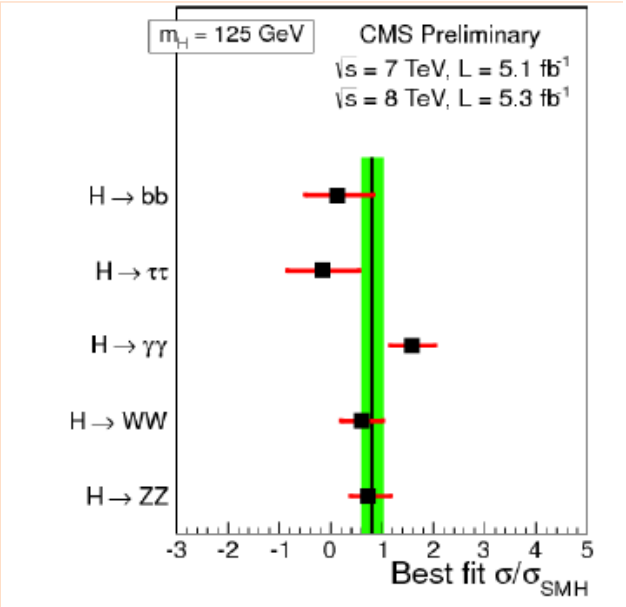


- Sensitive to SM in 14 TeV run, possible to constrain non-standard Higgs (e.g. pseudo-scalar) with 2012 data

- Big thanks to experimental colleagues at ANL for many helpful discussions!

SM Higgs? Branching Fractions

- Hints of deviations in branching fractions, some low (fermions) and some high (gamma gamma)?
- In the extreme that there is no coupling to fermions, then gg → H does not occur; and we must rely on associated production H(W,Z) and VBF.

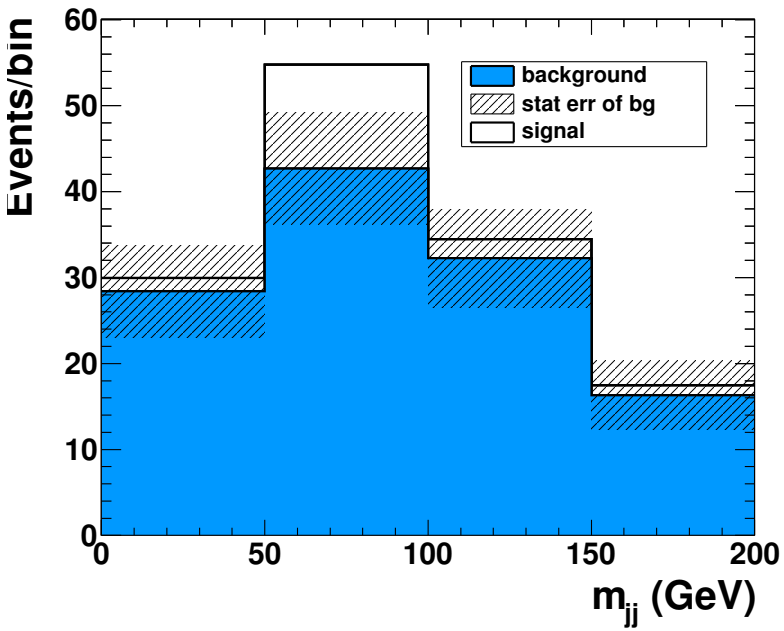


Full simulation of H(W,Z) at 7 TeV, with H → gam gam, and (W,Z) → jet jet:

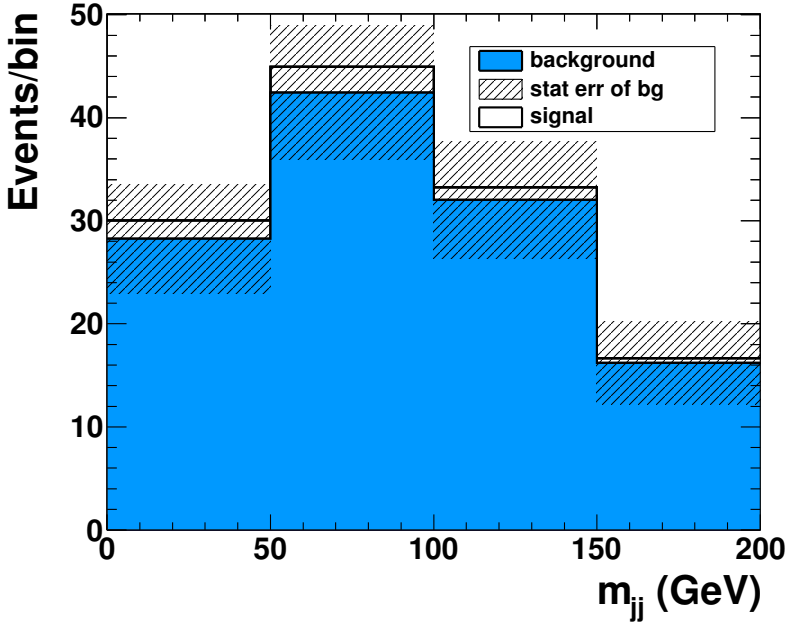
Berger, Zack Sullivan, Hao Zhang, arXiv: 1203.6645 PR D86 (2012) 015011

(W,Z) → j j mass distribution

Fermiophobic Higgs



SM Higgs



- We expect a clear vector boson mass peak for fermiophobic Higgs.
  - SM Higgs has no discernible signal.

Berger, Zack Sullivan, Hao Zhang, arXiv: 1203.6645 PR D86 (2012) 015011

Top Physics

Top Quark Polarization and the Search for New Physics

- Ed Berger, Qing-Hong Cao, Chuan-Ren Chen. Jianghao Yu, and Hao Zhang
  arXiv: 1201.1790, Phys. Rev. Lett. 108, 072002 (2012);
  arXiv: 1207.1101 (July 2012) PRL, to be published.

New physics interpretations of the top quark rapidity asymmetry at the Tevatron -- what, in addition, do we learn from the rapidity asymmetry of the decay lepton?

$$\mathcal{A}_{\rm FB}^{\ell} = \frac{N(q_\ell y_\ell > 0) - N(q_\ell y_\ell < 0)}{N(q_\ell y_\ell > 0) + N(q_\ell y_\ell < 0)}$$

- Theoretically - for the same top quark momentum distribution, a left-handed top quark and a right-handed top quark lead to different lepton charge asymmetries
- If we know the momentum and spin direction of the top quark, what is the probability that the decay lepton is in the forward (backward) region in the laboratory frame? Analytic derivation

From Top AFB to Lepton AFB

- SM: equal number of left-handed and right-handed top quarks in the final state:
- SM: $\frac{A_{FB}^{\ell}}{A_{FB}^{t}} \approx \frac{0+0.8}{2} = 40\%$

D0

$$A_{FB}^{t} = 0.196 \pm 0.065$$

$$A_{FB}^{\ell} = 0.152 \pm 0.040$$

$$\frac{A_{FB}^{\ell}}{A_{FB}^{t}} \sim 75\%$$

(1) Conclude: new physics must produce more right-handed top quarks (e.g. W' exchange with r-h couplings)

(2) Need full D0 data set; CDF confirmation

- * Important to measure both top and lepton AFB *

LHC Rapidity Asymmetry Data

CMS result on AFB (ttbar) agrees with SM; no need for NP. ATLAS data exceed SM

$$A_C^{t\bar{t}} = 0.029 \pm 0.018(\text{stat.}) \pm 0.014(\text{syst.})$$

$$A_C^{\ell\ell} = 0.023 \pm 0.012(\text{stat.}) \pm 0.008(\text{syst.})$$

ATLAS-CONF-2012-057

$$A_C^{t\bar{t}} = 0.004 \pm 0.010(\text{stat.}) \pm 0.011(\text{syst.})$$

CMS Collaboration, arXiv: 1207.0065

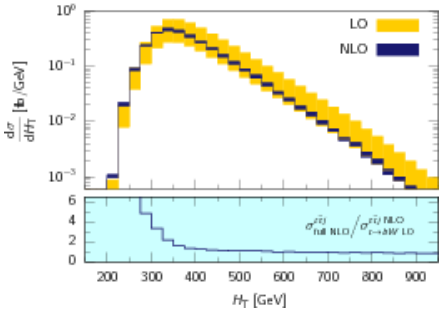
$$A_C^{t\bar{t}\ \text{SM}} = 0.006, \quad A_C^{\ell\ell\ \text{SM}} = 0.004$$ MC@NLO

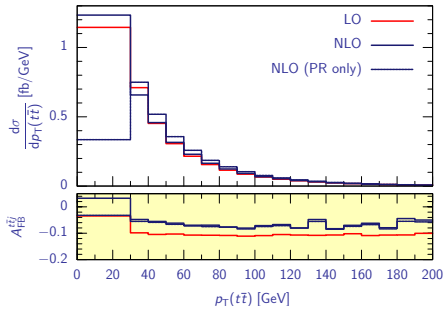
- We can obtain an estimate of AFB (ttbar) at the LHC by extrapolating from the Tevatron and applying the gg dilution
- The LHC value should be about 10% of the Tevatron
- ATLAS value agrees with the Tevatron asymmetry

- **NLO QCD corrections to production and decay of ttbar+jet**

  K. Melnikov, A. Scharf, M. Schulze. Nov 2011. Phys.Rev. D85 (2012) 054002

  Important SM process for studying pT spectrum of ttb pair, AFB and SUSY background.
  This is the first calculation that includes corrections in decay and jet radiation off decay products.





- **Finite-width effects in ttbar production and decay at the LHC.**

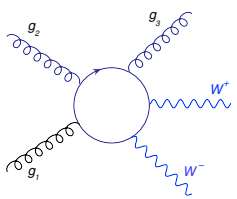
  A. Denner,S.Dittmaier,S.Kallweit,S.Pozzorini,M. Schulze. Mar 2012. SM and NLO Multileg Working Group

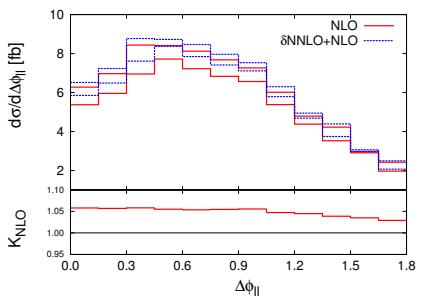
  Study of off-shell and non-resonant contributions at NLO QCD for important observables.

- **Gluon fusion contribution to W^+W^-+jet production.**

  T. Melia, K. Melnikov, R. Rontsch, M. Schulze, G. Zanderighi. May 2012. JHEP 1208:115 (2012)

  First calculation of the loop induced process gg → WWg which is the main background in the H+jet search channel.

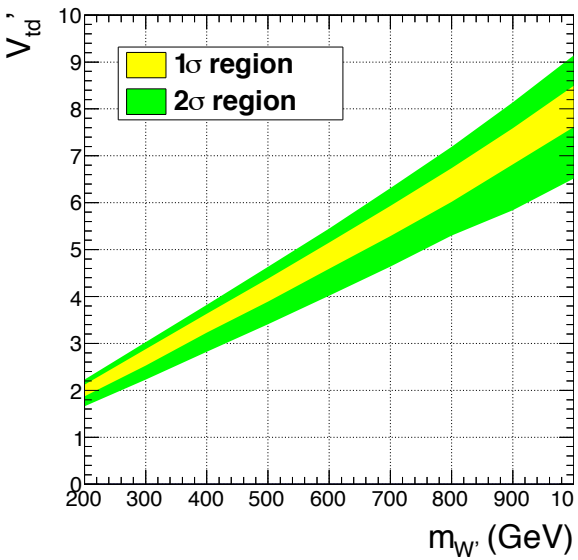


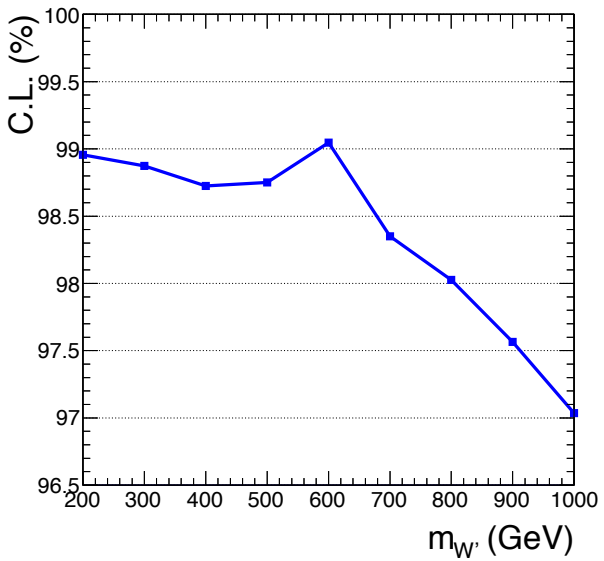


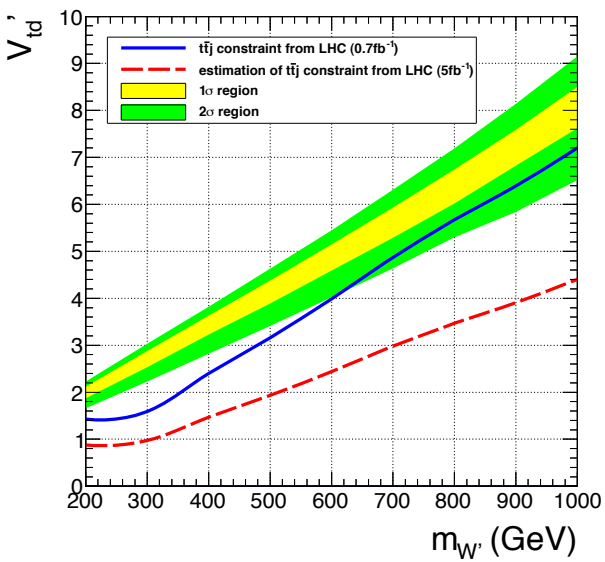
Flavor Changing W' model and top quark asymmetry

Daniel Duffty, Zack Sullivan and *Hao Zhang*, Phys. Rev. D **85** (2012)094027

- A deviation of forward-backward asymmetry in top quark pair production from the SM prediction is reported by Tevatron. It may be a hint of new physics.
- Flavor changing W' model is proposed to explain this anomaly. $\mathcal{L} = \frac{g}{\sqrt{2}} V'_{td} \bar{d} \gamma^\mu P_R t W'_\mu + h.c.$
- We fit the top pair production cross section and the forward-backward asymmetry at Tevatron. (Left figure)
- With the ttbar plus 1 jet data from the LHC, we find that the W' model is disfavored by the data (middle and right figures) and will be excluded when there are more integral luminosity at the LHC (right figure, red dashed line).







Relevant QCD Computations

- A subtraction scheme for NNLO calculations

  Boughezal, Melnkiov and Petriello, Phys. Rev. D85 (2012) 034025

  - A long-standing goal of the theory community is the ability to compute 2→2 processes at NNLO. Numerous applications: dijet, Higgs+jet, V+jet.
  - With our approach, this is for the first time possible for processes with both initial and final-state collinear singularities. This is necessary to describe any jet production process at NNLO.
  - Work in progress by R. Boughezal, M. Schulze and F. Petriello toward Higgs+jet at NNLO

- ttbar+$E_{T,miss}$ signatures at the LHC Work in preparation by R. Boughezal and M. Schulze

  - ATLAS and CMS assume leading-order decay predictions and neglect spin correlations in their studies of TT→ttbar+ XX signatures. How much does this affect the analysis?
  - Performing a full NLO study of production plus decay for several representative models. First time performed at this detailed level for a new physics model. A similar neglect of NLO in decay was shown to have a significant effect on top-quark predictions.

Neutrino Physics

Argonne NATIONAL LABORATORY

C Zachos (ANL), EPL 99 (2012) 11001.

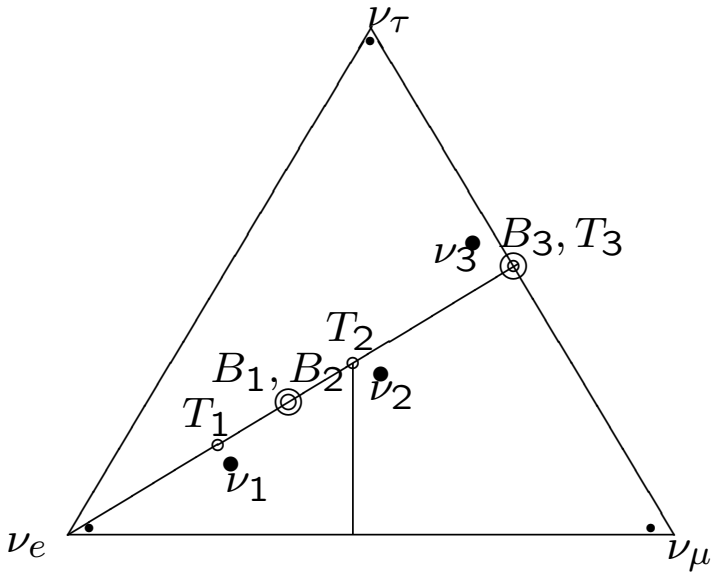
TERNARY PLOTS FOR NEUTRINO MIXING

▶ The unitary PMNS neutrino matrix U mixes left-handed fields of the three neutrino mass eigenstates ν_j, $i = 1, 2, 3$, into lepton-flavor linear combinations ν_l, $l = e, \mu, \tau$, named after the charged leptons they couple to,

$$\boxed{\nu_l = \sum_{j=1}^{3} U_{lj}\ \nu_j}\ .$$

All three angles in quark mixing are **small**: $\theta_{12} \approx \pi/14 \approx \lambda \approx 0.23$, $\theta_{23} \approx \lambda^2 \approx 0.04$, $\theta_{13} \approx \lambda^3 \approx 0.01$. By sharp contrast, for neutrino mixing, the reactor one is small, $\theta_{13} \approx 0.16 \pm 0.02$, and ***two are big***, the solar $\theta_{12} \approx (\pi/4 - 0.19) \pm 0.02$, and the atmospheric $\theta_{23} \approx (\pi/4 + 0.00) \pm 0.09$. "Popsicle plots", where the relative three flavor contents are depicted by different color sections adding up to a constant, do not make evident how they contrast among themselves.

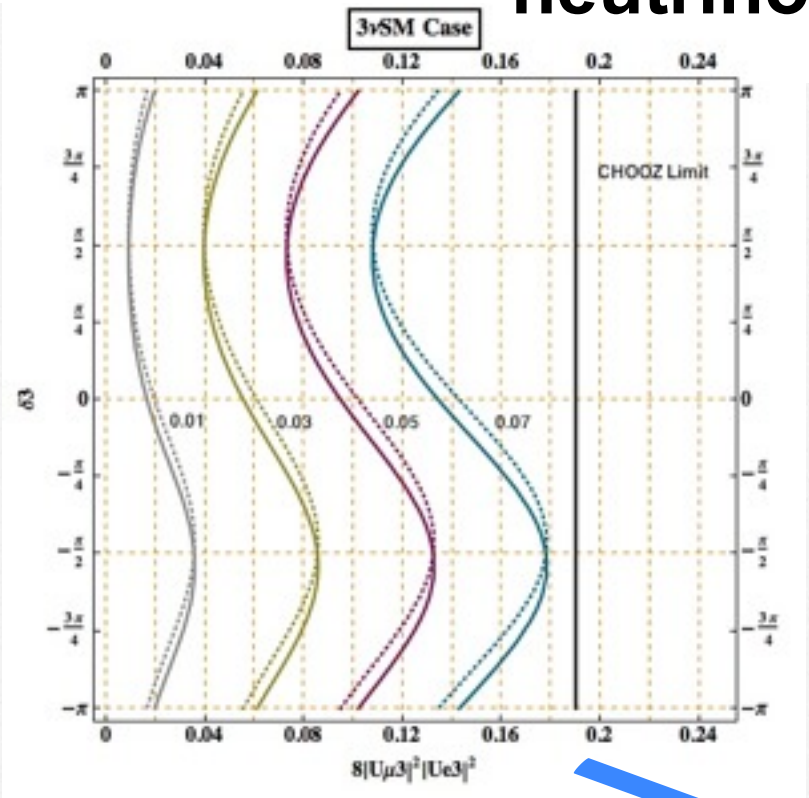
✓However, the ***unitarity constraints*** of PMNS are incorporated automatically in ***ternary plots*** (Dalitz plots): barycentric coordinates allow three variables with a fixed sum to be plotted as mere **points** inside an equilateral triangle on a plane and to be thus visually compared collectively.

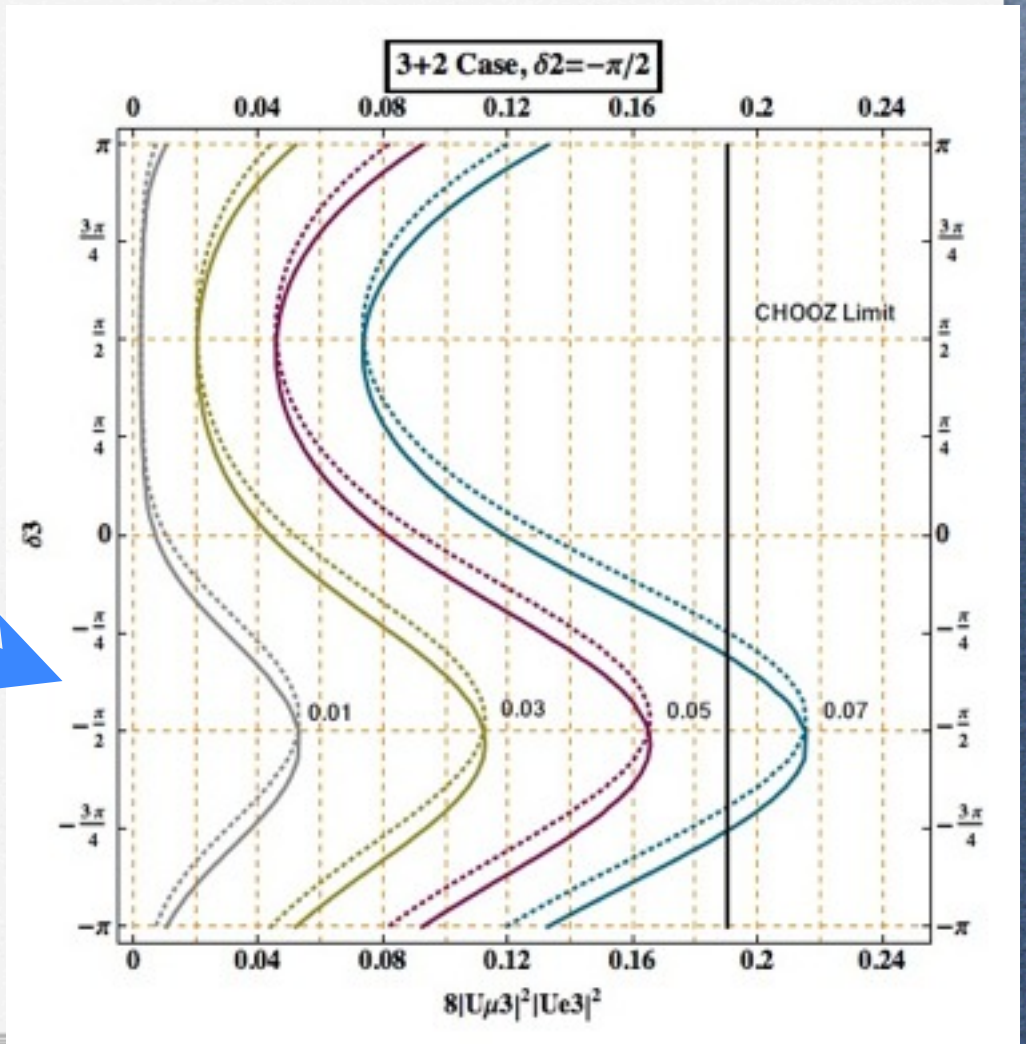


▶ The components of the constrained 3-vectors $N_j = (|U_{ej}|^2, |U_{\mu j}|^2, |U_{\tau j}|^2)$. The B_j (bimaximal), T_j (tribimaximal) mixing paradigms require $\theta_{13} = 0$ and maximal $\theta_{23} = \pi/4$; thus, they lie on the $\nu_\mu \leftrightarrow \nu_\tau$ approximate symmetry axis. The midpoint T_2 is the center of the equilateral triangle. (The small solid circles near the vertices represent the three quarks. Since the largest angle, the Cabbibo angle, is of the order of magnitude of θ_{13}, they are clustered near the vertices of the triangle by amounts comparable to the offset of ν_3 from the triangle side.) ↬ Such collective contrasts would be **unwieldy in tabular or popsicle plots**.

⇝ Ability to visualize mixing models.

Implication of sterile neutrinos for long-baseline neutrino experiments





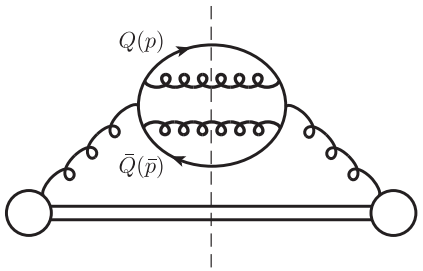
B. Battacharya, A. Thalapillil, C. Wagner, arXiv:1111.4225

Quarkonium Physics

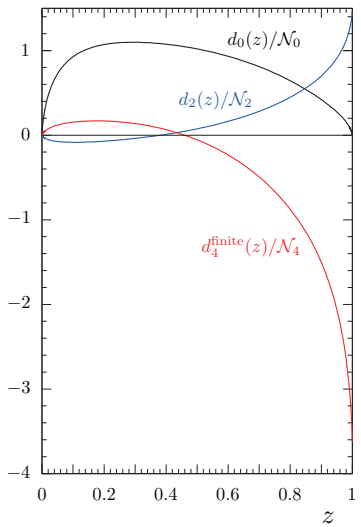
Relativistic Corrections to Gluon Fragmentation into J/ψ

G.T. Bodwin, U-Rae Kim, Jungil Lee, arXiv:1208.5301 (41pages)

- Challenging calculation conceptually and technically.
- First quarkonium calculation involving double IR divergences and two-loop operator renormalizations.
- Validates the NRQCD factorization approach at two loops.



- Surprising (factor 48) enhancement found in order-v^4 short-distance coefficient compared to order-v^0 short-distance coefficient.
- Caused mostly by peaking near $z = 1$: remnant of IR divergences.
- Too small to affect phenomenology at the current level of precision.

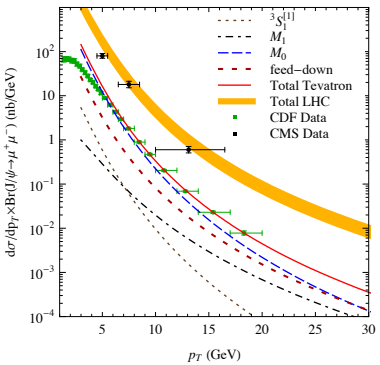


$$(\mathcal{N}_0, \mathcal{N}_2, \mathcal{N}_4) = (10^{-3}/m^3, 10^{-2}/m^5, 10^{-2}/m^7)\alpha_s^3$$

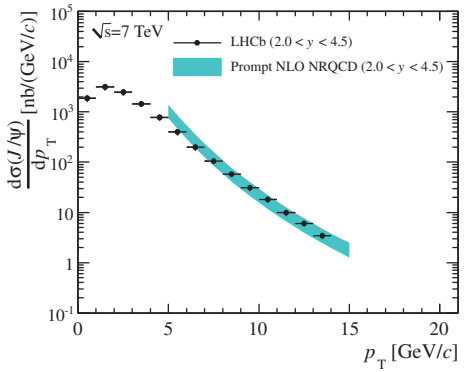
Theory of Quarkonium Production

G.T. Bodwin, arXiv:1208.5506 (25 pages)

- Extensive summary based on invited review talk for the Charm 2012 Workshop.
- The NRQCD factorization approach is very successful at describing cross sections at the Tevatron and predicting cross sections at the LHC, RHIC and Belle.

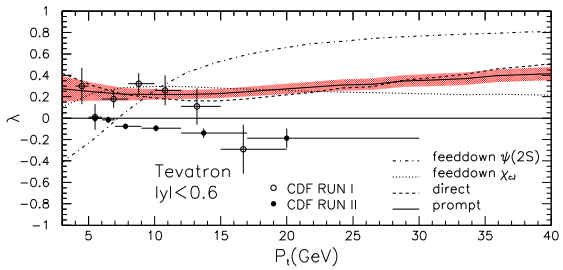


Ma, Wang, Chao, PRL 106, 042002 (2011)



LHCb Coll., EPJC 71, 1645 (2011)

- But the polarization predictions disagree with the CDF Run II results.



Gong *et al.*, arXiv 1205.6682

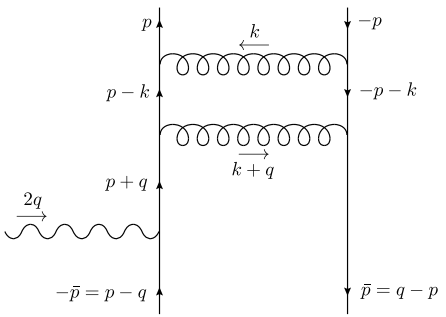
- Experimental results are inconsistent.
- Need LHC measurements of polarization.
- Helping CMS to prioritize measurements, make physics case.

The Puzzle of Double Logs in $e^+e^- \to J/\psi + \eta_c$

G.T. Bodwin, Hee Sok Chung, Jungil Lee

- Unexpected large double logs of Q^2/m_c^2 appear in NLO calculations of $e^+e^- \to J/\psi + \eta_c$.

- Detailed calculations show that the double logs arise from:
  - Sudakov double logs, which cancel in the sum over 20 diagrams.
  - An extra endpoint log times a light-cone evolution log. (Endpoint logs come from $z \sim 1$.)



- New insight into the origins of endpoint logs in terms of leading pinch surfaces.
- May solve long-standing problem of all-order organization of endpoint logs.
  - All orders resummation of large endpoint logs.
  - More powerful factorization results for light mesons, *e.g.*, B-meson weak decays.

Soft-collinear Gluons and Factorization in SCET

G.T. Bodwin, John Collins

- Bodwin and Collins constructed a two-loop example (inclusive meson production at high p_T) in which the factorization program of Soft-Collinear-Effective Theory (SCET) fails.
- This is a major hole in the widely used SCET approach.
- Demonstrates the need for more powerful techniques than SCET. Diagrammatic methods needed to establish factorization theorems, and to produce reliable calculations.

Resummation of Large Logs in Charmonium Production

G.T. Bodwin, Jungil Lee

- Large logs of p_T^2/m_c^2: Probably the largest uncalculated correction to charmonium production at high p_T. Important for high-p_T at the LHC.
- Bodwin and Lee are applying their methods, developed several years ago for LO calculations, to resum these logs to all orders in perturbation theory.
- Techniques applicable to other composite states, *e.g.*, BSM.

Formal Physics

▶ RG Flows, Cycles, and c-theorem Folklore, T Curtright, X Jin, and C Zachos, *Phys Rev Lett* **108** (2012) 131601.
Demonstration of periodicity of physics with respect to scale changes in Quantum Field Theory.

▶ Quantum Mecℏanics in Phase Space, T Curtright and C Zachos, *Asia Pacific Physics Newsletter* **1** (2012) 37-46.
Inaugural Issue. First, ever, history of the subject.

Postdocs

- The HEP Theory Group has been very successful in the supervision of postdocs.
- Most of the recent Argonne postdocs have found excellent positions and carried on successful careers after their stay at Argonne.
- For instance, most recent postdocs, Q.H. Cao, C.R. Chen have secured faculty positions at Beijing and Taiwan Normal University and G. Shaughnessy, J. Gainer and S. Quackenbush have secured postdoc positions at the Univ. of Wisconsin, Madison, the University of Florida, and Florida State University, to continue their high quality research activities.

Ed Berger -- Recent Community Activities

1. Chair, Committee on Constitution & Bylaws, American Physical Society.

2. Search Committee, Senior Computational Scientists, Argonne

3. Co-Organizer, ATLAS Physics Jamboree on Boosted Objects, Argonne, October 20, 2011.

4. Scientific Program Organizing Committee, Rencontres de Moriond, QCD and High Energy Hadronic Interactions, La Thuile, Italy, March 2011, 2012.

5. Organizing Committee, CTEQ Summer School, 2011 and 2012.

Seminars and Presentations since October 2011

1. "Search for New Physics at the Energy Frontier", Physics Department Colloquium, Wichita State University, Wichita, Kansas, November 9, 2011.

2. "NLO Predictions for W b b Production via Double Parton Scattering at the LHC", invited plenary talk at the 3rd Workshop on Multipartonic Interactions at the LHC (MPI11), DESY, Hamburg 21-25 November 2011.

3. "Double Parton Scattering at the LHC", invited plenary talk, Chicago 2012 Workshop on LHC Physics, Gleacher Center, Chicago, May 2, 2012.

4. "Double Parton Scattering", CDF Seminar, Fermilab, May 30, 2012.

5. "Top Quark Polarization and the Search for New Physics", invited plenary talk, conference on Beyond Standard Model of Particle Physics, Qui Nhon Vietnam, July 15 - 21, 2012.

6. "Higgs and SUSY in Vietnam -- Some 2012 Highlights", invited Summary Talk, conference on Beyond Standard Model of Particle Physics, Qui Nhon Vietnam, July15 - 21, 2012.

G. Bodwin Community/Leadership Activities & Awards

- Quarkonium Working Group (QWG)
  - A group of over 100 theorists and experimentalists working in quarkonium physics.
  - Interactions among theorists and experimentalists to identify and solve outstanding problems.
  - Topical Summer School and 8 International Workshops. 9th Workshop in Beijing, April 2013.
  - Two extensive reviews: hep-ph/0412158 (521 pages); arXiv:1010.5827 (181 pages).
  - Bodwin has been an overall and production-group convener of the QWG since 2005.
- Convener for Heavy Quarks, International Conference on Quark Confinement and the Hadron Spectrum in 2006, 2008, 2010, 2012.
- Author, "Quarkonium Hadroproduction," (December 2011).
  17 page document used by the CMS Collaboration to prioritize measurements and make physics case for trigger rates.
- U. of Chicago/Argonne Distinguished Performance Award (2010).
  For research in QCD and leadership in quarkonium physics.
- Eigenvector Method for fitting NRQCD matrix elements to data.
  Private communication adopted by all groups doing NLO quarkonium calculations.
  Yields correct error estimates, better predictive power.
- Recent Invited Plenary Talks
  - BNL Workshop on Quarkonium Production, June–6-18, 2011. (3 talks.)
  - CTEQ-LPC Workshop, FNAL Nov. 17–18, 2011.
  - Charm 2012, Honolulu, May 14–17, 2012.

R. Boughezal
Activities and Community Service

- Organized Conferences and Workshops:
  - LoopFest X: radiative corrections for the LHC and future colliders, Evanston, 2011
  - The Next Stretch of the Higgs Magnificent Mile: Chicago, 2012
  - Impact of Higgs Discovery: Argonne HEP retreat (upcoming in October 2012)
  - ISMD 2013 - International Symposium on Multiparticle Dynamics (to be held in Chicago)

- Invited Talks:
  - LoopFest XI, Pittsburgh, 2012
  - Chicago 2012 workshop on LHC physics
  - Quark confinement and the hadron spectrum X, Munich, 2012
  - Seminars at the University of Michigan, SLAC, Johns Hopkins 2011
  - DPF2011, Providence
  - Physics at the LHC 2011, Perugia

Ian Low's community activities:

- Invited seminars at UC Berkeley, U. Maryland, William and Mary, U. Chicago, Southern Methodist Univ., and SLAC.
- Invited colloquia at U. Chicago and LBNL (Research Progress Meeting).
- Invited talks at CERN LHC Theory Institute, CERN TeV4LHC workshop, Pittsburgh PACC Higgs workshop, ICTP workshop on strongly coupled physics in Italy, MCTP Higgs workshop in Ann Arbor, Chicago 2012 LHC workshop.
- LOC of SUSY 2011 in Fermilab. Co-chair of LOC of ANL-NU Higgs workshop. Co-organizer of KITP Rapid Response Workshop on Higgs in December of 2012.
- Co-convener of SUSY 2012 "Exotic/Alternative" session. Scientific Adviser of KITP 2013 Workshop on LHC physics.

Frank Petriello's community activities (2012)

- Continued leadership of the LHC Higgs Cross Section Working Group Gluon-Fusion group, with a mandate from ATLAS and CMS to provide numbers and recommendations for use in official studies; Editor, gluon fusion chapter, of two recent Yellow Reports: arXiv:1101:0593, 1201.3084
- Co-convenor, Snowmass 2013 QCD working group
- 2011-2012 NSF LHC Theory Initiative selection committee
- Co-organizer, 2012 and (upcoming) 2013 LoopFest conferences in Pittsburgh and Tallahassee
- Lectures on Higgs physics at the 2012 SLAC Summer Institute, and on QCD at the 2012 CERN-Fermilab Hadron Collider Summer School
- Invited conference and workshop talks at the University of Chicago, the MCTP; invited seminars and colloquia at IIT and LBL
- Graduate student Ye Li ⇒ postdoctoral position at SLAC

C.E.M. Wagner Community Activities

- Chair, SUSY Summer School, University of Chicago, August 24--26, 2011
- Convener, Proton Decay Group, Intensity Frontier Workshop, November 30--December 2, 2011
- Convener, Higgs Physics Group, LHC Workshop, Chicago, May 2--4, 2012
- Organizer, Higgs Discovery Implications Workshop, Chicago, Nov. 12--14, 2012
- Organizer, Workshop on Baryogenesis, KITP, June--August, 2014.

Invited Talks :

• Summary Talk, SUSY 2011, Fermilab

• Invited Plenary Talks at CERN, Perugia LHC Workshop, GGI Workshop, Mainz University, Karlsruhe University, Univ. of Chicago, BNL Workshop, Pittsburgh Workshop, LHC Forum and Michigan Workshop on Higgs Physics.

• Plenary Talk at Planck 2012 and Crete Conference on Implications of the Enhanced Higgs Diphoton decay rate.

• Plenary Talk at the BLV Workshop in Gatlinburg and Invited Talk at UC, Irvine on Electroweak Baryogenesis.

• Plenary Talk on Proton Decay at the Intensity Frontier Workshop and at LBNE Meeting at Argonne.

Honors & **Community service of C Zachos**

Member of the APS Heineman Prize Selection Committee, 2011 & 2012.

Session organizer (New Ideas & Developments) for the *Miami 2011 Conference*, 15-20 December, Ft Lauderdale, FL; Chair of 12/15/12 PM session: http://server.physics.miami.edu/∼cgc/Miami2011.html

Member of the Advisory Panel (in lieu of Editors) of J Phys A: Mathematical and Theoretical (IOP)— recommendation of referees on appeal.

Konopinski Physics Colloquium, Univ of Indiana, Bloomington, IN, October 26, 2011: "Quantum Mechanics Lives & Works in Phase Space"

Elected Fellow of the American Physical Society (DPF), November 2010,
"For significant theoretical contributions to supersymmetry, and for pioneering investigations of fundamental mathematical structures underlying a broad range of physical systems".

Summary

- Theory Group carries a Broad Research Program.
- Emphasis on the connection of Theory with Experiment.
- The group develops programs which are being used by the Tevatron and LHC experimental collaborations.
- Work on all aspects of Higgs, Top Quark and Quarkonia physics, from QCD corrections, to properties, flavor physics, model building and collider phenomenology. Also relevant work on Neutrino and Formal physics.
- Group activities widely recognized by numerous invited talks and awards : Four senior members are APS Fellows : E. Berger, G. Bodwin, C.E.M. Wagner and C. Zachos
- Successful supervision of postdocs and students.
- Members of the Theory Group have also been active in the organization of conferences and workshops, both at the local level, as well as at the international one.